



Five Organizational Features That Enable Successful Interdisciplinary Marine Research

Jessica Blythe^{1*} and Christopher Cvitanovic^{2,3}

¹ Environmental Sustainability Research Centre, Brock University, St. Catharines, ON, Canada, ² Australian National Centre for the Public Awareness of Science, Australian National University, Canberra, ACT, Australia, ³ Centre for Marine Socioecology, University of Tasmania, Hobart, TAS, Australia

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*Correspondence:

Jessica Blythe
jblythe2@brocku.ca

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To generate innovative solutions for marine sustainability challenges, scientists, policymakers, and funders are increasingly calling for interdisciplinary research that transcends disciplinary boundaries. However, challenges associated with doing interdisciplinary research persist and undermine progress toward tackling the complex challenges faced by marine social-ecological systems. One barrier for engaging in effective interdisciplinary research is a lack of understanding about the institutional capacities that support interdisciplinary knowledge production. Based on in-depth qualitative interviews with members of the Centre for Marine Socioecology in Australia, we identify five principles that underpin effective interdisciplinary research organizations. The principles are: (1) support female leadership; (2) forge partnerships outside of academia; (3) develop impact-based performance metrics; (4) focus on long-term funding; and (5) cultivate a visible brand. Going forward, these principles could be used to inform organizational design that transforms institutional barriers into enablers of innovative interdisciplinary research for more sustainable, desirable, and equitable futures.

Keywords: interdisciplinary research, anthropocene, sustainability, interdisciplinary institutions, institutional capacity, Australia

INTRODUCTION

As we progress into the Anthropocene, societal well-being and environmental sustainability are increasingly uncertain (Nash et al., 2017; Steffen et al., 2018; Lam et al., 2020). While the academic community historically sought to address such challenges within the confines of a single scientific discipline, it is now widely accepted that this approach to knowledge generation is no longer adequate (Brondizio et al., 2016). As Crow and Dabars (2017, p. 482) articulate, “biologists alone cannot solve the loss of biodiversity, nor chemists in isolation negotiate the transition to renewable energy.”

Instead, the unique challenges presented by the Anthropocene to marine socio-ecological systems necessitate new approaches of knowledge production that are capable of integrating scientific disciplines to develop solutions for complex challenges that are desirable, equitable, and viable (Castree et al., 2014; Bai et al., 2016; Bennett et al., 2019a,b; Nash et al., 2020). Increasing support for interdisciplinary research is reflected by a growing number of local to global programs that seek to address global sustainability challenges through interdisciplinary research

(Van Noorden, 2015). In 2019, for example, the United Kingdom's Research and Innovation body announced over \$260 million in funding for 12 Global Research Hubs over 5 years, including the One Ocean Hub, which involves 56 partner organizations across 11 countries (United Kingdom Research and Innovation, 2019b). Given the potential of integrative forms of research, sustainability scientists have shifted from asking *whether* interdisciplinary research is essential to asking *how* we can best build interdisciplinary research organizations that facilitate joint problem solving (Brown et al., 2015).

Despite increasing rhetorical support for interdisciplinary research, however, significant challenges associated with doing interdisciplinary research remain (Roy et al., 2013; Cundill et al., 2019a). For example, numerous studies have explored the challenges associated with integrating divergent academic disciplines in a meaningful way, such as those associated with different “languages” and research methodologies of individual disciplines (e.g., Blythe et al., 2017; Alexander, 2019). Navigating such roadblocks requires additional resources, which in itself has proven problematic, and in extreme cases, has led to destabilizing tensions within research teams (Frusher et al., 2014). Bammer (2017) argues that the specific personal and relational skills needed to operate effectively as part of an interdisciplinary research process are poorly defined, recognized, and rewarded within existing academic institutions.

In response, an emergent body of literature has sought to identify strategies for overcoming the documented barriers to building capacity for interdisciplinary research (reviewed in section “Enablers of Interdisciplinary Research: Current Knowledge and Critical Gaps” below). A dominant theme throughout this literature has been identifying pathways to build the capacity of interdisciplinary researchers (e.g., Haider et al., 2018; Hein et al., 2018; Kelly et al., 2019). While such studies have helped to understand how best to cultivate individual researchers that are capable of engaging effectively within interdisciplinary research processes, there is very little empirically derived guidance for how to build institutional capacity and structures that support interdisciplinary research, particularly for research organizations focused on developing solutions to marine sustainability challenges (Cvitanovic et al., 2020). The identification of core principles to guide such efforts can be achieved through the evaluation of existing interdisciplinary efforts, which in turn can help generate guidance for other research organizations seeking to enhance their interdisciplinary capabilities (e.g., Cvitanovic et al., 2018a).

Thus, the aim of this study is to begin to identify core principles for building effective interdisciplinary research organizations for tackling complex marine sustainability challenges. We address this aim via an in-depth evaluation of the Centre for Marine Socioecology (from here on CMS) in Tasmania, Australia, which brings together disciplinary expertise in physics, law, economics, biology, sociology and governance to solve the grand challenges facing the world's coastal and marine environments. In focusing on a single case study, we are able to clarify the key perspectives of CMS members across all disciplines and career stages (PhD students, post-doctoral researchers, mid-level and senior academics, and the leadership

team) so as to generate a comprehensive initial set of principles underpinning interdisciplinary success (e.g., Cvitanovic et al., 2016b). Undertaking an in-depth evaluation then allows for future efforts to compare the results across multiple cases to evaluate the applicability of the identified principles in other contexts and settings (Reed et al., 2014; Norström et al., 2020).

ENABLERS OF INTERDISCIPLINARY RESEARCH: CURRENT KNOWLEDGE AND CRITICAL GAPS

Given the challenges of undertaking interdisciplinary research, there is a need to better understand how to develop the capacities—from individual to institutional—that support effective interdisciplinary research (Roy et al., 2013; Mitchneck et al., 2016). Here, we provide a brief review of the existing research, to highlight progress to date and situate our study amongst this broader body of literature.

A key theme throughout the emerging literature on supporting interdisciplinary research has been the need to build individual capacity for interdisciplinarity (e.g., Haider et al., 2018; Hein et al., 2018; Kelly et al., 2019; Andrews et al., 2020). Research suggests that interdisciplinary researchers tend to be motivated to contribute to the advancement of a “common good,” characterized by attitudes of tolerance and reflexivity and by skills including team management and facilitation, among other attributes (Guimarães et al., 2019). Another important individual capacity is the extent and quality of team members' past collaborative experiences with each other and their experience with collaboration in general (Misra et al., 2011). Research is showing that individual collaborative capacities are not simply intuitive, but rather must be carefully developed through processes of collaborative learning (Freeth and Caniglia, 2020). To this end, Kelly et al. (2019) offer ten tips designed to help students and early career researchers develop interdisciplinary competencies. The first tip, for example, advises students to develop an area of expertise before attempting interdisciplinary research. However, debate remains as to whether specialized disciplinary training is an essential prerequisite for an individual's efforts in cultivating interdisciplinary competencies (Stokols, 2014).

Research has also identified that relational capacities are crucial for interdisciplinary innovation and performance. Relational capacities are defined as the interpersonal dynamics that shape the process and outcomes of collaborative initiatives (Cundill et al., 2019a). Interpersonal trust is considered an essential relational capacity for the success of interdisciplinary initiatives (Pischke et al., 2017). For example, trust allowed members of the Resilience Alliance to engage in high-impact collaborative research over more than a decade (Parker and Hackett, 2012). Power dynamics also shape the performance of interdisciplinary research teams. For example, power asymmetries can prevent some actors from playing an active role in collaborative processes, which undermines one of the core tenants of interdisciplinarity (Cundill et al., 2015). However, even when the individual and relational capacities described here are

present in interdisciplinary teams, emerging research suggests that institutional factors also strongly influence the outcomes of interdisciplinary efforts (Cundill et al., 2019b).

Interdisciplinary knowledge production depends on institutional contexts (Van Noorden, 2015; Mitchneck et al., 2016). For example, in the Oxford Handbook on Interdisciplinarity, Crow and Dabars (2017, p. 476) argue that “despite broad consensus regarding the imperative for inter- and transdisciplinary approaches to inquiry, twenty-first-century academic culture remains defined by the organization and practices established by this set of historically determined institutions.” In response to these barriers, researchers have begun to focus on identifying institutional capacities that support interdisciplinarity. Institutional capacities refer to the cultures, practices and structures of research organizations (Mitchneck et al., 2016). There are a number of areas where supportive institutional practices can impact the productivity and effectiveness of interdisciplinary research (Andrews et al., 2020). Examples include division of overhead between departments and provision of administrative support for the increased coordination that is required for conducting multi-departmental or multi-institutional research (Misra et al., 2011). Cundill et al. (2019b) also identify the alignment of institutional cultures as critical for supporting interdisciplinary knowledge production. Yet, empirical studies on the institutional capacities required to support interdisciplinary research remain limited (Crow and Dabars, 2017). Thus, we see institutional capacity as a key, but often underexplored, dimension of enabling high-quality interdisciplinary research and promoting impact on the ground, particularly in relation to marine sustainability challenges.

MATERIALS AND METHODS

Data Collection

To develop principles for building effective interdisciplinary research organizations we employed a qualitative research approach. Qualitative methods are considered advantageous over quantitative methods for achieving this objective as they allowed us to establish an in-depth understanding of the perceptions of each study participant (Bryman, 2012). Further, qualitative research approaches have previously proven effective for identifying the key principles underpinning the success of research processes, which in turn allows for the establishment of design principles that can inform the efforts of other research teams and organizations (e.g., Reed et al., 2014; Marshall et al., 2017; Norström et al., 2020).

We selected the Centre for Marine Socioecology (CMS) as the case for this study as it embodies the key features of interdisciplinary research organizations (Creswell and Poth, 2016). Here, we define interdisciplinary research as inquiry that involves collaboration among scholars from multiple scientific disciplines to advance research approaches and theories to understand and address complex social-ecological challenges (adapted from Roy et al., 2013). In using this definition, interdisciplinary research is distinguished from other commonly used terms such as multidisciplinary science (which is additive

opposed to integrative) and transdisciplinary science (which also includes non-academic forms of knowledge). We define research organizations as collectives of people oriented toward solving shared tasks, which include universities, research institutions, and research groups (following Perrow, 1979).

In order to select participants with a deep understanding of interdisciplinary research organizations who could best inform our research question, we followed a criterion sampling protocol (Creswell and Poth, 2016). Members of CMS were invited to participate in the study based on two criteria: (a) they had to have been members for at least 12 months and (b) they had to be “active members.” In this regard, active members were those who regularly attended CMS meetings, seminars and events, and contributed to the CMS community. Participants were identified through consultation with key CMS staff (e.g., administrative support role and Director) and through meeting minutes where attendance was recorded. At the time of the study there were 48 CMS members across all career stages, but only 27 who qualified as “active members.” Of the active members, 18 were female and 9 were male. Past members were excluded to ensure that all participants were reflecting on the current structure of CMS (e.g., current director, aims, research themes, etc.). Others (e.g., non-active members) were excluded on the basis that whilst they had joined the CMS they had not taken any part in any CMS initiatives, and thus were not well placed to reflect on the aspects of CMS that contribute to its operation, successful or otherwise.

Interviews began with “the most active” CMS members, and continued until theoretical saturation was reached, meaning that the adequate depth of information had been achieved and no new data was generated by additional interviews (Patton, 2002). While there is no universally appropriate sample size for qualitative interviews, best practices suggest that saturation tends to occur after 12 interviews, while meta-themes are often present after six interviews (Guest et al., 2006; Baker and Edwards, 2012). In total, 18 of the 27 “active members” of the CMS were interviewed (thus representing 67% of the active members), composed of PhD students ($n = 7$), post-doctoral researchers ($n = 3$), mid-career scientists ($n = 4$), and members of the leadership team ($n = 4$). Where possible, interviews were conducted face to face, however, for logistical reasons some interviews were conducted either via Skype or phone.

All interviews were guided by a set of open-ended questions (e.g., an interview guide) that were designed to explore the perceptions of participants against the study objectives (full interview guide at **Supplementary Material**). The interview guide itself was developed following grounded theory guidelines (Charmaz and Belgrave, 2012) and by drawing on previous efforts to characterize principles of success (i.e., Reed et al., 2014; Cvitanovic et al., 2018a; Kelly et al., 2019), but adapted to suit the specific aims of this study. As such, the interview guide focused on four key areas. Specifically, it was designed to assess the perceptions of participants regarding:

1. The establishment, goals, and operation of the CMS;
2. The extent to which they felt the CMS had achieved meaningful interdisciplinary research processes, and the

extent to which that new knowledge had been used to influence policy and practice;

3. The barriers they had experienced working in an interdisciplinary research environment; and
4. The key lessons that they had learnt relating to how to ensure success within interdisciplinary research teams and organizations.

To ensure the utility of the interview guide, it was first pilot tested among three members of the CMS and refined accordingly. Changes were minor, and focused on improving the wording of questions for clarity, opposed to the intent of the actual question. While we acknowledge that in some circumstances it may not be appropriate to pilot the interview guide on individuals who are part of the focal research group (Bryman, 2012), the specific nature of our case study made it important to ensure that the questions were clear and applicable to the specific context (following previous studies such as Cvitanovic et al., 2016b, 2018a).

Data Analysis

All interviews were digitally recorded and professionally transcribed to ensure their accuracy. To allow for principles to emerge from the data, without the limitations that can be imposed by deductive coding approaches, we employed an inductive coding approach based on Grounded Theory Analysis (Glaser and Strauss, 1967; Charmaz and Belgrave, 2012). Interview transcripts were coded using NVIVO 10 qualitative data analysis software.

To improve the accuracy of the coding, both researchers started by independently coding the same four transcripts. Coding results were then discussed and high levels of overlap among the emergent themes were present. Where minor divergence was evident, it was discussed and a course for resolution jointly agreed. Following this, a single author (JB) coded the remaining interviews.

Following Grounded Theory Analysis, all interview transcripts were coded through an “*in vivo*” coding method during the first cycle of coding (Charmaz, 2008). By using the participants’ own words to derive and summarize key themes, the “*in vivo*” coding approach allowed participants perspectives to emerge without the constraints imposed by more structured methodologies (Hay, 2010). To ensure the validity and relevance of themes that emerge through this approach, the evolving interpretations were continually verified against the raw data from which they were derived (following Fleming and Vanclay, 2009; Marshall et al., 2011). This coding process resulted in 27 codes.

Following the initial coding of raw data, a second cycle of coding was undertaken. During this step in the analysis, data was re-coded following a thematic coding technique in order to develop a coherent synthesis of key themes (Saldaña, 2015). Thematic coding refers to the identification and interpretation of patterns, or “themes,” in qualitative data that are relevant to the research question (King et al., 2018). We selected thematic coding as an appropriate approach for the second round of coding, as we sought to identify common patterns or themes within

our participants’ perspectives the characteristics of effective interdisciplinary research organizations. This iterative process resulted in 12 sub-themes and five main themes that were directly derived from the data (summarized in **Table 1**). As with the initial phase of coding, to ensure that emerging themes were valid and relevant, the evolving interpretations were continually verified against the raw data from which they were derived. This approach of deriving themes and sub-themes to ensure that results are both rigorous and representative is well established in the literature (for example, see Reed et al., 2014; Cvitanovic et al., 2016a; Kelly et al., 2019; Norström et al., 2020).

RESULTS AND DISCUSSION

Through the coding process we identified five key principles (i.e., the main “themes” derived from the coding process) for building effective interdisciplinary research organizations (**Figure 1**). The principles are: (1) support female leadership, (2) forge partnerships outside of academia, (3) develop impact-based performance metrics, (4) focus on long-term funding, and (5) cultivate a visible brand. We recognize that the principles are not discrete, they interact. Moreover, the order of presentation is not indicative of importance. In this section, we describe each principle by drawing on the 12 sub-themes that emerged during data analysis (sub-themes summarized in **Table 1**). We then situate our findings within the broader literature to identify and discuss the key insights that our study provides for building effective interdisciplinary research organizations. In doing so we also identify specific actions for scientists, policymakers, and funders to help support the achievement of each principle.

Principle 1. Support Female Leadership

The first of our five principles highlights the importance of supporting female leadership across all levels, from centre directors to project and research group leaders. When developing interdisciplinary research organizations, the results of our analysis suggest that it is critical that women are supported to both attain, and to be successful in, leadership positions. Our results suggest that doing so can (i) encourage innovation, (ii) cultivate a more inclusive research environment, and (iii) remove hierarchical power imbalances that have the potential to derail collaboration among researchers from different disciplines. Here, we discuss these findings in the context of research on gender studies from other sectors, as well as emerging evidence from sustainability science.

First, our analysis indicates that in the case of the CMS, female leadership across the organization has driven innovation and creativity, both of which are necessary for identifying novel solutions to contemporary sustainability challenges. For example, one participant in our study reflected:

“It is important to have a channel for that continual refresh and to always be trying to think how can we bring in something new or what could we be doing different? Or where could we get some new ideas? I’m glad to see that [the female director] is definitely driving that view and hopefully, that will continue, and I think that that’s really important for other interdisciplinary centres as well.”

TABLE 1 | Five principles for building effective interdisciplinary research organizations identified through the coding process.

Principle	Coding frequency	Example quote from interviews
Sub-principle		
1. Support female leadership		
Foster innovation	70	"[Our director] has an open and inspiring kind of attitude that is forward-looking...being open to all disciplines and really encouraging and setting up meetings or processes for people to work with new people is so important. And I do think there was a gender component, which was really important" (Interview 18)
Nurture a culture of inclusion	42	
Share power horizontally	21	
2. Forge partnerships outside of academia		
Engage in knowledge co-production	15	"What we need is more of those in between roles, knowledge brokers, people who can be more embedded with the decision-makers and get inside those systems" (Interview 3)
Involve science-policy boundary-spanners (such as knowledge brokers)	16	
Create trust through partnerships	11	
3. Develop impact-based performance metrics		
Develop interdisciplinary indicators	21	"[We need to] have some real tangible outputs and promote those like crazy, so people can see...something is coming out of this" (Interview 15)
Demonstrate impact	2	
4. Seek long-term funding		
Identify innovative funding	44	"Somewhere like Sweden, for example, they can achieve such fantastic centres of research, because they have incredible philanthropic funding that is really quite long-term. Something like that here would be a real game changer" (Interview 18)
Shift from project funding to long-term funding	49	
5. Cultivate a visible brand		
Identify your unique identity	50	"You need people to recognise you. You need brand and you need credibility" (Interview 12)
Promote your brand (e.g., via non-traditional venues such as social media)	15	

These principles and the sub-principles were derived from qualitative data generated from interviews with 18 members of the Centre for Marine Socioecology in Tasmania, Australia, following Grounded Theory Analysis.

**FIGURE 1** | Five principles for building effective interdisciplinary research organizations to tackle complex marine social-ecological challenges. The principles were derived from qualitative data generated from interviews with 18 members of the Centre for Marine Socioecology in Tasmania, Australia, following Grounded Theory Analysis. The order and color of presentation is not indicative of importance.

It's not just mixing a few disciplines and then that's it. It really is about trying to do everything essentially differently and creating a whole new environment, so that you can achieve true innovation" (Interview 18)

Indeed, the majority of respondents reflected on the positive influence of CMS' female director on innovation within the

center, and attributed that influence directly to her gender. Thus, the experiences of members of the CMS suggests that teams led by women, and that are inclusive of diverse perspectives, may be more likely to generate novel ideas for solving intractable sustainability problems.

The positive relationship between the presence of women in leadership positions and innovation is well documented in

the business and corporate sectors (Apesteguia et al., 2012; Lückers-Rovers, 2013). In Spain, for example, Díaz-García et al. (2013) observed that gender diversity within Research and Development teams foster radical innovations in technology firms. In Denmark, a study of 1648 companies documented enhanced innovation resulting from gender diversity within leadership roles (Østergaard et al., 2011). While the positive influence of women leaders is well established in other sectors and settings, in academia it remains relatively understudied. There are, however, a few notable exceptions. For example, Nielsen et al. (2018) recently found that gender diversity can drive scientific discovery. They attribute the boost in innovation to the cognitive diversity associated with gender balanced teams. They describe cognitive diversity as the varied ways in which women frame problems, which can drive creative solutions for complex challenges (Nielsen et al., 2018).

Second, our analysis suggests that within the CMS, female leadership was a critical factor in fostering a culture of inclusion, trust, and mutual respect. For example, one participant described how creating an inclusive environment is essential for interdisciplinary teams:

"You really have to have leadership that tries to develop a culture that is inclusive and allows people to experiment in working in different ways because they are not working in a set disciplinary way with set rules and expectations. There has got to be an expectation that sometimes you will do things that will fail, sometimes you will do things that won't work but that's okay because that is what this interdisciplinary work is about and that's what the director sort of embraces" (Interview 16)

As highlighted by Ledford (2015), inclusion, trust and respect are critical for successful interdisciplinary collaboration (Ledford, 2015). This finding aligns with other emerging research that has shown that feelings of inclusion, respect and trust are vital for building effective interdisciplinary research teams and organizations (Cvitanovic et al., 2018b). Similarly, in reflecting on more than a decade of interdisciplinary water research, Brown et al. (2015) attribute successful collaboration to leaders who nurtured empathy and respect between team members.

Third, our analysis found that female leaders across different levels within the CMS context (e.g., director, group leaders, and team leaders) were perceived as highly effective at creating horizontal power structures that dismantle traditional hierarchies. The necessity of shared power was highlighted by one respondent:

"...tolerance is needed in all directions, so it's not just tolerance across disciplines, it's tolerance by the older scientists to hear younger scientists with a valid opinion and a different experience to what you've got who are facing different challenges, but equally for the younger scientists to appreciate that they don't always know the whole political landscape that the older scientists are trying to navigate to keep the thing going. So, it just needs tolerance and happiness and willingness on all directions to really make the thing work" (Interview 17)

The removal of hierarchical power imbalances is particularly important within interdisciplinary research settings because it encourages all participants (irrespective of discipline, career

stage, or other factors) to contribute to all stages of the research process (Andrews et al., 2020). When power hierarchies are present, leaders (or other more senior people such as later career scientists) can either consciously or subconsciously steer research processes toward their own biases (e.g., discipline) and thus derail a collaborative research process.

Based on our findings, and the literature discussed here, it is clear that supporting women in leadership positions is a critical component of building successful interdisciplinary research organizations. Doing so, however, will require a number of strategies that challenge outdated academic cultures (e.g., Howe-Walsh and Turnbull, 2016). One approach for supporting female leadership is through mandatory gender bias training. For example, Mitchneck et al. (2016) propose a six-point plan for promoting diversity within academic institutions, which includes gender bias training to better inform the campus community about hurdles to hiring, retaining, and promoting women and changing promotion and tenure timeline to better support early career women. Similarly, Nielsen et al. (2018) outline specific management techniques for building gender diversity across four scales: research teams, disciplines, research organizations, and society. Techniques include cultivating positive beliefs about diversity and developing formal policies that link funding to team diversity (Nielsen et al., 2018).

Another way to support female leadership within interdisciplinary research organizations is through gender quotas. For example, a recent experimental study found that gender quotas increased the equity and efficiency of climate policy interventions (Cook et al., 2019). While gender quotas can be subject to challenges, such as provoking backlash against women (Leibbrandt et al., 2017), they nevertheless represent a tangible strategy for promoting gender balance within academic institutions and warrant further consideration as well as exploration of how they can be most effectively integrated into organizational settings.

Our first principle proposes that female leadership can stimulate innovation and support inclusive research environments where hierarchies are dismantled. Before moving on, we want to point out an important caveat associated with the first principle. A risk associated with advocating for women in leadership positions and gender balance is that "female 'difference' is used as the basis to stereotype capabilities and cast them in a collective negative light" (Díaz-García et al., 2013, p. 157). In other words, unfavorable typecasts about female leadership can be used to characterize all female academics as possessing the same traits. Therefore, we would like to qualify our first principle by stressing that the diversity of female leadership styles and women as academics should always be recognized.

We would also like to emphasize that, in no way, does this principle suggest that good leadership is constrained to a single gender. Nor does it suggest that all leaders must be female. Rather, this principle, which was derived from our data and the specific case of CMS, highlights that female leadership at different levels within the CMS led to several benefits relating to culture and inclusion. This finding supports an existing body of literature, as

highlighted above, about the importance of gender diversity and inclusion more broadly in academia. However, further work is needed to more comprehensively understand the importance and influence of gender (and we suggest diversity and intersectionality more broadly) in terms of their influence on interdisciplinary success, particularly in terms of teamwork and leadership.

Principle 2. Forge Partnerships Outside of Academia

The second principle highlights the importance of forging partnerships outside of universities. Our results suggest that when academics collaborate with actors from outside of academia (for example, with policy makers or industry representatives), both the quality of the scientific outputs, as well as their relevance to decision-makers, increased. For example, one respondent described how diverse viewpoints can drive holistic problem framing:

“...that [workshop] was really great because we had people from law, marine ecology, psychology, broader social sciences, and that generated really exciting conversations...it was one of those times where it was super beneficial to be like ‘I didn’t even think about the international commission on X, but thank goodness our collaborator from law is here to remind us of that’” (Interview 11)

Previous work has argued that it is difficult, if not impossible, for any single individual or disciplinary group to develop a complete picture of solution pathways and the dynamics of potential impacts and unintended consequences they may entail (Castree et al., 2014; Blythe et al., 2017). Thus, achieving holistic interdisciplinary research on multiple, interacting stressors on social-ecological systems necessitates the inclusion of a range of stakeholders, perspectives and knowledge systems (Cornell et al., 2013; Bennett et al., 2016; Cinner et al., 2016), not just academic knowledge systems. Moreover, collaboration between individuals with widely different, even polarized, perspectives has been shown to generate higher quality research than traditional disciplinary approaches alone (Shi et al., 2019).

Partnerships that extend beyond the academy are also essential for supporting research that understands and informs decision-making processes (Cvitanovic et al., 2016b). This is critical as successfully tackling complex social-ecological challenges cannot be achieved through knowledge generation alone, but rather, the way in which new knowledge is applied to achieve tangible changes in theory and on practice (Reed et al., 2014). As one interviewee pointed out, strictly academic research questions do not necessarily produce information that can inform effective decision-making:

“We [academics] need to solve the problems they [decision-makers] want solved, so you do need to solve the problems we think need to be solved but you also need to solve the ones that they want solved, because that’s not always the same” (Interview 12)

Thus, it is clear that researchers must engage in meaningful two-way knowledge exchange with decision-makers and other stakeholders outside of academia. Doing so is critical for

achieving both policy-relevant science, as well as evidence-informed decision-making processes (reviewed in Cvitanovic et al., 2015).

Our results specifically identified two strategies for working across knowledge systems. The first is the implementation of knowledge co-production, and the second is the use of science-policy boundary-spanners, such as knowledge brokers. The first of these sub-principles (i.e., co-production) is centered around notions of participatory research approaches (e.g., Meadow et al., 2015; Djenontin and Meadow, 2018). As defined by Norström et al. (2020), knowledge co-production is an iterative process that brings together diverse types of expertise, knowledge and actors to interactively produce new context-specific knowledge and pathways toward a sustainable future. This is achieved by actively engaging decision-makers and other relevant stakeholders (and knowledge systems) throughout the research process to ensure that they can contribute their knowledge experience and insights into all phases of the research activity including problem identification, framing and formulation (Cvitanovic et al., 2019).

The second strategy identified through our analysis for forging partnerships outside of academia is the practice of “boundary-spanning.” Here, we define boundary spanning following Bednarek et al. (2018, p. 1176) as “work to enable exchange between the production and use of knowledge to support evidence-informed decision making in a specific context” and boundary spanners as the “individuals or organizations that specifically and actively facilitate this process.” The importance of boundary spanning within the CMS was highlighted by one participant, who said:

“If you’re looking to inform policy and practice then you need to have contacts and networks within the policy sphere and people who can work towards—so having people who can act as kind of a broker role is really important...someone to be able to translate from both sides to make it as successful as possible” (Interview 10)

Within the sustainability sciences literature many types of boundary spanning functions have been identified, ranging from individual knowledge brokers (e.g., Reinecke, 2015; Cvitanovic et al., 2017) to large-scale boundary organizations (e.g., Bednarek et al., 2015; Hart et al., 2015; Meyer et al., 2015). Evidence suggests that when implemented effectively, boundary spanning efforts can, among other things, successfully facilitate new networks and partnerships among researchers and non-academic partners, as well as facilitate the exchange of knowledge throughout these networks (Posner and Cvitanovic, 2019).

Finally, our results also identified the need to build trust when engaging with partners outside of academia, and how this can be achieved by engaging partners from problem formation all the way through the research project. This was reflected by one respondent in our study who pointed out that engaging with partners before establishing a collaborative project can be useful to develop positive, trusting relationships:

“What I’ve learned is sometimes it’s good to make contacts without making a bad impression. With the fisheries managers, I was able to meet them through volunteering just going and talking to kids about catching fish, which was a really good way to get a foot in the door and get to know the right people without offering them more than

I could deliver or making a bad impression because I didn't know what it was that I was working on yet" (Interview 11)

Establishing trust has been identified as a critical pre-condition underpinning the success of research efforts that involve partners from outside of academia (Cvitanovic and Hobday, 2018). Building trusting relationships requires careful navigation as collaborators are getting to know one another, and to avoid the potential pitfalls of situations associated with a loss of trust, or even too much trust (reviewed by Lacey et al., 2018).

Principle 3. Develop Impact-Based Performance Metrics

The third principle identified through our analysis is the need to develop impact-based performance metrics. Impact in this context refers to research influence that extends outside the academy to achieve “an effect on, change or benefit to the economy, society, culture, public policy or services, health, the environment or quality of life, beyond academia” (United Kingdom Research and Innovation, 2019a). This is separate from the notion of academic impact, which describes the intellectual contribution of an individual (or group of individuals) to a particular field of study (Penfield et al., 2014) and is typically measured through metrics associated with publication rates, citations rates and other indices such as the h-index (Ravenscroft et al., 2017). This distinction is important for interdisciplinary research organizations that are explicitly oriented toward the identification of socially relevant solutions to complex social-ecological challenges (Lang et al., 2012). Thus, their central objective is not simply the pursuit of knowledge, but rather the pursuit of knowledge that informs how societies navigate associated with complex challenges such as climate change, biodiversity loss, water scarcity, and food insecurity (Nash et al., 2017; Pecl et al., 2017).

Calls for new metrics to adequately capture impact outside of the academy are not new. For example, Porter et al. (2006) identify the need to tailor promotion and tenure to account for interdisciplinary research contributions in order to support knowledge integration within universities. Similarly, a recent assessment of an interdisciplinary research team in Sweden, whose core goal is to link scientific knowledge to action to support the sustainable management of the Baltic Sea, identified the lack of suitable metrics as a key barrier to achieving tangible impacts on policy and practice (Cvitanovic et al., 2018a). Yet, despite widespread recognition of the need for new impact-based performance metrics, measuring interdisciplinary impact remains problematic (Palmer, 2018). This is associated with the ambiguity associated in defining what actually constitutes “impact” outside of the academy, the long time-lags between knowledge production and impact (i.e., often greater than 10 years), and the non-linear and multi-casual pathways by which impact can occur (Molas-Gallart et al., 2000; Chowdhury et al., 2016; Reed et al., 2018). In combination, these factors make it difficult to attribute an impact to an individual or team of interdisciplinary researchers, limiting

progress to the development and implementation of novel impact-based metrics. The challenges associated with measuring practical impacts was highlighted by one study participant who said:

“Success is only a term. So we can discuss what success means for you. In the science world I would say success is publishing a lot of papers and I think we're doing quite well in this area. But we're also doing quite well in the non-scientific world with this open dialogue and just try to engage with stakeholders. And also in engaging with different disciplines. And I think this is, also, kind of success, just different, maybe harder to evaluate because you don't have an impact factor” (Interview 2)

Despite these difficulties, our analysis of participant experiences in the CMS identified two focal areas that could assist in the development of new impact-based performance metrics. First, participants in our study highlighted the need to develop explicitly *interdisciplinary indicators* to support monitoring and evaluation (M&E) frameworks. This was considered particularly important since the contributions of solution-oriented interdisciplinary research organizations can be missed by more traditional academic metrics (Stern, 2016). Specifically, the types of indicators suggested by CMS members included measures relating to the amount of time spent undertaking activities relating to science engagement and outreach, indicators to capture changes in social networks (e.g., to quantify growth in the network, increases in the cohesion of the network, or enhanced trust among members of the network), and formal recognition of non-academic publications (e.g., reports to industry or government) on equal footing with peer-reviewed publications. While this list is not exhaustive, it does show that it is indeed possible to develop new impact-based indicators of success and highlights the need for future research to more comprehensively understand what these indicators could entail (Maag et al., 2018).

Building on the above, participants in our study also highlight that making progress toward impact-based performance metrics will also require the identification of novel ways of actually *reporting impact*. Specifically, reporting frameworks for interdisciplinary research might include non-traditional metrics, such as case studies, testimonials from partners, and other more qualitative measures of impacts on policy and practice (Brown et al., 2015). Indeed, this supports recent evidence associated with the UK Research Excellence Framework (REF), which utilized narrative style case studies to help illustrate the impacts achieved by interdisciplinary research projects (Stern, 2016). Reflecting on the importance of impact assessment frameworks, like the UK's REF, a participant in this study noted:

“In the UK they have the Research Excellence Framework process, where you have to do impact case studies. Each organisation does an impact case study to look at how their research is contributing to policy or contributing to management change or things like that... it would be really useful for CMS to go through that process, and actually identify if the research is actually contributing to management in whatever form that may be of industry or of conservation practice” (Interview 15)

Operationalizing these principles, and building the capacity of interdisciplinary research organizations to demonstrate real-world impact, will require institutional change. A main obstacle for interdisciplinary researchers is the fact that academic reward systems are still largely organized along disciplinary divisions (Hicks et al., 2010). As Belcher et al. (2016, p. 14) articulate “the lack of a standard and broadly applicable framework for the evaluation of quality in [interdisciplinary research] is perceived to cause an implicit or explicit devaluation of high-quality [interdisciplinary research] or may prevent quality [interdisciplinary research] from being done.” That is, the lack of institutional recognition for research impact outside the academy can discourage researchers from engaging in solution-oriented, collaborative research (Shanley and López, 2009). Early career researchers may be particularly disincentivized to strive for impact outside the academy since early career stages tend to be characterized by short-term contracts and job insecurity (Evans and Cvitanovic, 2018). Indeed, the requirement to return a fixed number of outputs per individual may encourage a focus on “safer” publication strategies, and this may involve short-termism in individual researchers’ research strategies to enhance the likelihood of career progression and obtaining permanent employment (Stern, 2016). Thus, making meaningful progress toward impact-based performance measures must be underpinned by significant institutional reform among academic agencies to recognize and reward science engagement and outreach efforts in parallel with academic achievements (Cvitanovic et al., 2015).

Principle 4. Focus on Long-Term Funding

The fourth principle highlights the need to secure long-term funding to support successful interdisciplinary research. Funding plays a pivotal role in enabling academics to undertake high-quality research in all fields and disciplines, supporting a range of research items and activities, including field and laboratory costs, the salaries of PhDs and post-doctoral researchers, training and partnerships (Lyll et al., 2013). The importance of long-term funding (e.g., > 5 years), however, is even more important within interdisciplinary research settings given the additional time required, and associated transactional costs, to build meaningful relationships founded upon mutual respect and trust among research team members (Cvitanovic et al., 2019). This is perhaps best described by Laura Meagher, an interdisciplinary coach in the UK, who reflected that “the most common mistake is underestimating the depth of commitment and personal relationships needed for a successful interdisciplinary project. You see people who think it’s not much more than stapling a bunch of CVs to the back of a proposal, they don’t realize that it takes time to build a relationship” (as quoted in Ledford, 2015, p. 310). Thus, conducting effective interdisciplinary research is often a long-term endeavor, which must be reflected in funding to allow the full development of relationships, and the actual (opposed to tokenistic) integration of different disciplines into the research process.

Our results highlight the ways in which long-term funding is particularly important during the design and establishment of an interdisciplinary research group. For example, as articulated by one participant:

“When [CMS] started out, there was funding to employ three Post Docs and pay for some PhD scholarships. there wasn’t any money in the budget to start some exciting collaborations and I think that that was a massive oversight. You need to have the funds to spend on research collaborations. You need the funds to be able to pay for someone in admin or communication who is going to really bring that sense together from a logistical point of view. So, I would say that thinking very carefully about the money you need to really create a tangible centre” (Interview 16)

As illustrated through this quote, ensuring adequate resources from the onset of an interdisciplinary endeavor is critical to facilitate the emergence of new collaborations, which in turn provides the basis for innovation, discovery and the advancement of knowledge. Securing long-term funding is also critical to allow the implementation of appropriate support processes, structures and resources that underpin success, such as the inclusion of communication and outreach experts to enhance the likelihood that research outputs are achieving real world outcomes.

Despite the importance of long-term funding to the success of interdisciplinary endeavors, interdisciplinary researchers have been challenged to secure funding. For example, a recent study that analyzed data from more than 18,000 proposals submitted to the Australia Research Council’s Discovery Programme found that interdisciplinary research has consistently lower funding rates than disciplinary research (Bromham et al., 2016). Likewise, the Global Research Council’s annual meeting identified a growing concern toward inadequate support for interdisciplinary research needed to address global challenges. The CMS specifically, for example, has been unsuccessful in two Transformation Research Hubs competition and one of the respondents attributes their failed record to the interdisciplinary nature of the center:

“The one place that I feel disappointed with CMS, and it’s not CMS’s fault, it’s actually a funding constraint. For two years running now we’ve put out what’s called a transformational training centre application in Australia, so that’s to try and have industry-oriented training of post-graduate students. And we keep getting bumped because they don’t get the idea of what the interdisciplinary stuff gives. It’s very clear that if you have an engineering innovation centre that’s teaching you engineering, what that brings, but it’s hard for the reviewers to understand what CMS would bring” (Interview 17)

Participants within our study highlighted that securing long-term funding to support innovative interdisciplinary research will require institutional reform by funders that explicitly recognize the additional challenges imposed by interdisciplinary research. Participants in our study identified longer-term grants and funding time together for collaboration as two promising pathways forward. Participants also highlighted the need for innovative funding models that support relationship building and provide opportunities for learning. Several respondents pointed to the National Socio-Environmental Synthesis Center (SESYNC) as a useful model, which employs an innovative funding model that supports newly formed collaborative teams to work together at its facility in the US to tackle complex challenges in novel ways (Palmer, 2018). We do, however, note that even funding schemes

like these, designed to support interdisciplinary research, can be challenging to obtain as highlighted earlier.

The need for longer-term grants is based on the recognition that interdisciplinary research typically takes longer than disciplinary research. Further, participants of our study also noted that most tangible impacts arising from interdisciplinary research often occur long after the research itself is complete. Yet, funding for interdisciplinary research often ends with a final project report, which misses the longer-term impact and sustainability of project outcomes (Blasiak et al., 2019). As such, longer-term funding would further enable the attainment of real-world impacts associated with interdisciplinary research (Blasiak et al., 2019).

Further, our results suggest that interdisciplinary research funding should also explicitly support face-to-face interactions between collaborators. As one respondent noted:

"The key point there is, it's not just funding for the research that we do that's necessary, but it's funding to create the socialising. Because, I mean, that's where the whole team gets together, and then the whole collaboration starts" (Interview 1)

Bridle et al. (2013) propose that interdisciplinary encounters are an effective means to support the development of future interdisciplinary researchers, with a major advantage of this approach being the opportunity for open communication. They recommend that "funding bodies and other members of the research community should take note of the effectiveness of encounters to foster interdisciplinarity and generate space to develop more innovative and high-impact research that delivers solutions to the challenges facing humanity in the future" (Bridle et al., 2013, p. 30).

Principle 5. Build a Visible Brand

The fifth and final principle that emerged from our analysis is the potential power of effective branding for supporting interdisciplinary research organizations. For example, one respondent noted:

"It feels that [CMS] has become quite well established in the eyes of the rest of the world. Where if we now mention the Centre for Marine Socioecology, it has a presence. . . The name is part of the brand, isn't it? I mean, in the full sense of the word, the brand has a whole thing sitting behind it. It makes the centre directed and stronger in its coherence" (Interview 9)

In this context, branding refers to the development of a unique name, design, and ethos that identifies and differentiates an organization (Vatsa, 2016). Developing a unique brand that clearly distinguishes an organization was considered by study participants as critically important given the present global proliferation of interdisciplinary research centres that share the broad goal of generating solutions to complex socio-ecological challenges.

Indeed, by looking across the existing literature it is clear that branding can play a pivotal role in building effective interdisciplinary research organizations. For example, research organizations can leverage a visible brand to establish their credibility, which in this context, refers to perceptions about

the high accuracy, validity, and quality of research outputs (Cvitanovic et al., 2018a). Research has shown that institutional credibility can increase the uptake of research findings into policy and practice (Cvitanovic et al., 2018a). Establishing credibility is particularly important for research organizations tackling complex social-ecological challenges that are rife with conflicting emotional, financial, social, and political interests (Blythe et al., 2018). Building academic credibility is even more important as the legitimacy of science and research is increasingly questioned. As Irwin and Horst (2016, p. 1), recently pointed out "it does seem that trust in experts is in short supply with many commentators suggesting that 'facts' are losing out in their battle with 'opinion'."

Second, branding and the associated credibility it can inspire, is an important mechanism through which to broaden the real-world impact of interdisciplinary research. One of the central goals of interdisciplinary sustainability research is to inform real-world solutions, and thus the knowledge generated must be communicated beyond the academy (Lang et al., 2012). Credibility is believed to be one of three key traits of scientific knowledge (the others being legitimacy and salience) that underpin its uptake and integration into decision-making processes (Cash et al., 2003). Thus, an effective brand that helps to cultivate organizational credibility can also improve the extent to which the knowledge generated within the organization supports evidence-informed decision-making processes.

While the development of a unique name and ethos underpins the establishment of a brand, our results also highlight the importance of *promoting* your unique brand. In particular, participants in our study identified the need to promote your brand via non-traditional academic venues, such as the publication of academic papers and presentations at academic conferences. One respondent pointed out that novel communication strategies are required to increase the reach and audience of interdisciplinary research:

"I don't think we need another report. I really struggle with the meaning of reports. Because they don't get read. So, I think that they are other ways to increase visibility. Twitter and those sorts of things. Social media is quite important, for sure" (Interview 1)

Indeed, many participants in our study reflected on the power of venues such as social media for building brand credibility and enhancing knowledge exchange. Evidence shows that research organizations with well-known and well-followed social media accounts, for example, can communicate research to a broad audience of other researchers, decision-makers, journalists, and the general public (Darling et al., 2013). For instance, a recent study found that scientists who Tweet to more than 1,000 followers reach non-academic audiences comprised of research and educational organizations, media, members of the public and decision-makers (Côté and Darling, 2018). Moreover, the audience of tweets can be amplified exponentially through sharing (re-tweeting) and shared via other social media platforms (Shiffman, 2012).

While the influence of effective branding is well documented in business and marketing research, empirical investigation of branding in social-ecological systems research is largely absent. This paucity suggests future research on effective branding

by research organizations represents a frontier for building effective interdisciplinary research organizations. For example, interdisciplinary scientists and organizations might learn how to build brand identity from well-established models in business or marketing (Ghodeswar, 2008).

CONCLUSION

In the context of the Anthropocene, interdisciplinary research is essential for identifying innovative solutions. In a recent review, Nicholas Stern concluded “as universities increasingly commit to addressing complex, intrinsically difficult “Grand Challenges” of global importance there is a clear recognition that *such issues and problems require a range of different perspectives that interdisciplinarity and collaboration can foster*” (Stern, 2016, p. 14, emphasis added). Despite broad consensus regarding the imperative for interdisciplinary approaches to inquiry, empirical evidence on how we can best build institutional capacity for interdisciplinary research is still lacking. Through in-depth, qualitative research this study identifies five principles pertinent to institutional design efforts to accommodate interdisciplinary research. The principles include: (1) support female leadership, (2) forge partnerships outside of academia, (3) develop impact-based performance metrics, (4) seek long-term funding, and (5) cultivate a visible brand.

While our investigation of the Centre for Marine Socioecology was a first step in generating empirically derived insights for building effective interdisciplinary research organizations, we would like to highlight several limitations that could be addressed in future research. Our case study focused on a single Australian organization, limiting the generalizability of our results and suggesting that our findings may be most applicable to organizations within similar contexts, such as Europe and North America. The principles may not translate to interdisciplinary organization in the Global South that operate in very different institutional contexts. Exploration of the applicability of these principles in other contexts represents an important area for future research. Indeed, the inclusion of more cases and authors from the Global South research has been identified an important frontier for marine interdisciplinary research (Blythe et al., 2020). Future work is also needed to more comprehensively understand each principle, and the institutional reforms needed for achieving them.

Irrespective, the five principles presented here represent a contribution to the important task of building interdisciplinary research organizations capable of tackling our most pressing challenges. In particular, our findings contribute to the growing body of literature on the institutional capacities that support interdisciplinary research organizations that engage in effective marine social-ecological systems research. We hope our findings might inform what Crow and Dabars (2017, p. 476) refer to as “institutional reconfiguration to promote interdisciplinarity.” However, in proposing common principles we do not wish to deny the complexity, diversity, and internal differences of interdisciplinary research organizations. Nor do we imply that these principles should serve as prescriptions of a set of design

strategies applicable in all contexts. Rather, we aim to call attention to the need for further research on institutional enablers of interdisciplinary research. Thus, we present these lessons from the Centre for Marine Socioecology in Australia as a starting point for further exploration and research into how to optimize the design and implementation of interdisciplinary research centres. Future engagement with these five principles, including exploration of how they translate across contexts, scales, and geographies, will be critical for building the interdisciplinary research capacity required to tackle our most pressing scientific and societal questions.

DATA AVAILABILITY STATEMENT

The datasets generated for this study are available on request to the corresponding author.

ETHICS STATEMENT

This study has been approved by the CSIRO’s Social Science Human Research Ethics Committee in accordance with the National Statement on Ethical Conduct in Human Research (2007). The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

JB and CC designed the research, collected and analyzed the data, and wrote the manuscript. Both authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/fmars.2020.539111/full#supplementary-material>

REFERENCES

- Alexander, K. (2019). Progress in integrating natural and social science in marine ecosystem-based management research. *Mar. Freshw. Res.* 70, 71–83. doi: 10.1071/mf17248
- Andrews, E. J., Harper, S., Cashion, T., Palacios-Abrantes, J., Blythe, J., Daly, J., et al. (2020). Supporting early career researchers: insights from interdisciplinary marine scientists. *ICES J. Mar. Sci.* 77, 476–485. doi: 10.1093/icesjms/fsz247
- Apesteguia, J., Azmat, G., and Iriberry, N. (2012). The impact of gender composition on team performance and decision making: Evidence from the field. *Manag. Sci.* 58, 78–93. doi: 10.1287/mnsc.1110.1348
- Bai, X., Van Der Leeuw, S., O'Brien, K., Berkhout, F., Biermann, F., Brondizio, E. S., et al. (2016). Plausible and desirable futures in the Anthropocene: A new research agenda. *Glob. Environ. Change* 39, 351–362. doi: 10.1016/j.gloenvcha.2015.09.017
- Baker, S. E., and Edwards, R. (2012). “How many qualitative interviews is enough,” in *Discussion paper*, (Manchester: National Center for Research Methods).
- Bammer, G. (2017). Should we discipline interdisciplinarity? *Palgrave Commun.* 3, 1–4. doi: 10.1057/s41599-017-0039-7
- Bednarek, A. T., Shouse, B., Hudson, C. G., and Goldburg, R. (2015). Science-policy intermediaries from a practitioner's perspective: The Lenfest Ocean Program experience. *Sci. Public Policy* 43, 291–300. doi: 10.1093/scipol/scv008
- Bednarek, A. T., Wyborn, C., Cvitanovic, C., Meyer, R., Colvin, R. M., Addison, P. F. E., et al. (2018). Boundary spanning at the science-policy interface: the practitioners' perspectives. *Sustainability Sci.* 13, 1175–1183. doi: 10.1007/s11625-018-0550-9
- Belcher, B. M., Rasmussen, K. E., Kemshaw, M. R., and Zornes, D. A. (2016). Defining and assessing research quality in a transdisciplinary context. *Res. Eval.* 25, 1–17. doi: 10.1093/reseval/rvv025
- Bennett, N. J., Blythe, J., Cisneros-Montemayor, A. M., Singh, G. G., and Sumaila, U. R. (2019a). Just transformations to sustainability. *Sustainability* 11:3881. doi: 10.3390/su11143881
- Bennett, N. J., Blythe, J., Tyler, S., and Ban, N. C. (2016). Communities and change in the anthropocene: understanding social-ecological vulnerability and planning adaptations to multiple interacting exposures. *Region. Environ. Change* 16, 907–926. doi: 10.1007/s10113-015-0839-5
- Bennett, N. J., Cisneros-Montemayor, A. M., Blythe, J., Silver, J. J., Singh, G., Andrews, N., et al. (2019b). Towards a sustainable and equitable blue economy. *Nat. Sustainability* 2, 991–993.
- Blasiak, R., Wabnitz, C. C., Daw, T., Berger, M., Blandon, A., Carneiro, G., et al. (2019). Towards greater transparency and coherence in funding for sustainable marine fisheries and healthy oceans. *Mar. Policy* 107:103508. doi: 10.1016/j.marpol.2019.04.012
- Blythe, J., Armitage, D., Alonso, G., Campbell, D., Dias, A. C. E., Epstein, G., et al. (2020). Frontiers in coastal well-being and ecosystem services research: a systematic review. *Ocean Coast. Manag.* 185:105028. doi: 10.1016/j.ocecoaman.2019.105028
- Blythe, J., Nash, K., Yates, J., and Cumming, G. (2017). Feedbacks as a bridging concept for advancing transdisciplinary sustainability research. *Curr. Opin. Environ. Sustainability* 26, 114–119. doi: 10.1016/j.cosust.2017.05.004
- Blythe, J., Silver, J., Evans, L., Armitage, D., Bennett, N. J., Moore, M. L., et al. (2018). The dark side of transformation: Latent risks in contemporary sustainability discourse. *Antipode* 50, 1206–1223. doi: 10.1111/anti.12405
- Bridle, H., Vrieling, A., Cardillo, M., Araya, Y., and Hinojosa, L. (2013). Preparing for an interdisciplinary future: a perspective from early-career researchers. *Futures* 53, 22–32. doi: 10.1016/j.futures.2013.09.003
- Bromham, L., Dinnage, R., and Hua, X. (2016). Interdisciplinary research has consistently lower funding success. *Nature* 534:684. doi: 10.1038/nature18315
- Brondizio, E. S., O'Brien, K., Bai, X., Biermann, F., Steffen, W., Berkhout, F., et al. (2016). Re-conceptualizing the Anthropocene: A call for collaboration. *Glob. Environ. Change* 39, 318–327. doi: 10.1016/j.gloenvcha.2016.02.006
- Brown, R. R., Deletic, A., and Wong, T. H. (2015). Interdisciplinarity: How to catalyse collaboration. *Nat. News* 525:315. doi: 10.1038/525315a
- Bryman, A. (2012). *Social Research Methods*. Oxford: Oxford University Press.
- Cash, D. W., Clark, W. C., Alcock, F., Dickson, N. M., Eckley, N., Guston, D. H., et al. (2003). Knowledge systems for sustainable development. *PNAS* 100, 8086–8091.
- Castree, N., Adams, W. M., Barry, J., Brockington, D., Büscher, B., Corbera, E., et al. (2014). Changing the intellectual climate. *Nat. Clim. Change* 4, 763–768.
- Charmaz, K. (2008). Grounded theory as an emergent method. *Handbook Emerg. Methods* 155:172.
- Charmaz, K., and Belgrave, L. (2012). “Qualitative interviewing and grounded theory analysis,” in *The SAGE Handbook of Interview Research: the Complexity of the Craft*, eds J. F. Gubrium, J. A. Holstein, and B. Amir (Oaks, CA: SAGE Publications, Inc), 347–365. doi: 10.4135/9781452218403.n25
- Chowdhury, G., Koya, K., and Philipson, P. (2016). Measuring the impact of research: Lesson's from the UK's Research Excellence Framework 2014. *PLoS One* 11:e0156978. doi: 10.1371/journal.pone.0156978
- Cinner, J. E., Pratchett, M. S., Graham, N. A. J., Messmer, V., Fuentes, M. M. P. B., Ainsworth, T., et al. (2016). A framework for understanding climate change impacts on coral reef social-ecological systems. *Region. Environ. Change* 16, 1133–1146.
- Cook, N. J., Grillo, T., and Andersson, K. P. (2019). Gender quotas increase the equity and effectiveness of climate policy interventions. *Nat. Clim. Change* 9, 330–334. doi: 10.1038/s41558-019-0438-4
- Cornell, S., Berkhout, F., Tuinstra, W., Tabara, J. D., Jäger, J., Chabay, I., et al. (2013). Opening up knowledge systems for better responses to global environmental change. *Environ. Sci. Policy* 28, 60–70. doi: 10.1016/j.envsci.2012.11.008
- Côté, I. M., and Darling, E. S. (2018). Scientists on Twitter: Preaching to the choir or singing from the rooftops? *Facets* 3, 682–694. doi: 10.1139/facets-2018-0002
- Creswell, J. W., and Poth, C. N. (2016). *Qualitative Inquiry and Research Design: Choosing Among Five Approaches*. Oaks, CA: Sage publications.
- Crow, M. M., and Dabars, W. B. (2017). “Interdisciplinarity and the institutional context of knowledge in the American research university,” in *The Oxford Handbook of Interdisciplinarity*, eds R. Frodemen and J. T. Klein (Oxford: Oxford University Press), 471–484.
- Cundill, G., Currie-Alder, B., and Leone, M. (2019a). The future is collaborative. *Nat. Clim. Change* 9, 343–345.
- Cundill, G., Harvey, B., Tebbott, M., Cochrane, L., Currie-Alder, B., Vincent, K., et al. (2019b). Large-scale transdisciplinary collaboration for adaptation research: Challenges and insights. *Glob. Challng.* 3:1700132. doi: 10.1002/gch2.201700132
- Cundill, G., Roux, D. J., and Parker, J. N. (2015). Nurturing communities of practice for transdisciplinary research. *Ecol. Soc.* 20:22.
- Cvitanovic, C., and Hobday, A. J. (2018). Building optimism at the environmental science-policy-practice interface through the study of bright spots. *Nat. Commun.* 9:3466.
- Cvitanovic, C., Colvin, R. M., Reynolds, K. J., and Platow, M. J. (2020). Applying an organizational psychology model for developing shared goals in interdisciplinary research teams. *One Earth* 2, 75–83. doi: 10.1016/j.oneear.2019.12.010
- Cvitanovic, C., Crimp, S., Fleming, A., Bell, J., Howden, M., Hobday, A. J., et al. (2016a). Linking adaptation science to action to build food secure Pacific Island communities. *Clim. Risk Manag.* 11, 53–62. doi: 10.1016/j.crm.2016.01.003
- Cvitanovic, C., Cunningham, R., Dowd, A.-M., Howden, S. M., and van Putten, E. I. (2017). Using Social Network Analysis to Monitor and Assess the Effectiveness of Knowledge Brokers at Connecting Scientists and Decision-Makers: An Australian case study. *Environ. Policy Gov.* 27, 256–269. doi: 10.1002/eet.1752
- Cvitanovic, C., Hobday, A. J., van Kerkhoff, L., Wilson, S. K., Dobbs, K., and Marshall, N. A. (2015). Improving knowledge exchange among scientists and decision-makers to facilitate the adaptive governance of marine resources: a review of knowledge and research needs. *Ocean Coast. Manag.* 112, 25–35. doi: 10.1016/j.ocecoaman.2015.05.002
- Cvitanovic, C., Howden, M., Colvin, R. M., Norström, A., Meadow, A. M., and Addison, P. F. E. (2019). Maximising the benefits of participatory climate adaptation research by understanding and managing the associated challenges and risks. *Environ. Sci. Policy* 94, 20–31. doi: 10.1016/j.envsci.2018.12.028
- Cvitanovic, C., Löf, M. F., Norström, A. V., and Reed, M. S. (2018a). Building university-based boundary organisations that facilitate impacts on environmental policy and practice. *PLoS one* 13:e0203752. doi: 10.1371/journal.pone.0203752
- Cvitanovic, C., McDonald, J., and Hobday, A. J. (2016b). From science to action: principles for undertaking environmental research that enables knowledge

- exchange and evidence-based decision-making. *J. Environ. Manag.* 183, 864–874. doi: 10.1016/j.jenvman.2016.09.038
- Cvitanovic, C., van Putten, E. I., Hobday, A. J., Mackay, M., Kelly, R., McDonald, J., et al. (2018b). Building trust among marine protected area managers and community members through scientific research: Insights from the Ningaloo Marine Park, Australia. *Mar. Policy* 93, 195–206. doi: 10.1016/j.marpol.2018.04.010
- Darling, E. S., Shiffman, D., Côté, I. M., and Drew, J. A. (2013). The role of Twitter in the life cycle of a scientific publication. *Ideas Ecol. Evol.* 6, 32–34.
- Díaz-García, C., González-Moreno, A., and José Sáez-Martínez, F. (2013). Gender diversity within R&D teams: Its impact on radicalness of innovation. *Innovation* 15, 149–160.
- Djenontin, I. N. S., and Meadow, A. M. (2018). The Art of Co-production of Knowledge in Environmental Sciences and Management: Lessons from International Practice. *Environ. Manag.* 61, 885–903. doi: 10.1007/s00267-018-1028-3
- Evans, M. C., and Cvitanovic, C. (2018). An introduction to achieving policy impact for early career researchers. *Palgrave Commun.* 4, 1–12.
- Fleming, A., and Vancly, F. (2009). Using discourse analysis to better inform the practice of extension. *Extens. Farm. Syst. J.* 5, 1–10.
- Freeth, R., and Caniglia, G. (2020). Learning to collaborate while collaborating: Advancing interdisciplinary sustainability research. *Sustainability Sci.* 15, 247–261. doi: 10.1007/s11625-019-00701-z
- Frusher, S. D., Hobday, A. J., Jennings, S. M., Creighton, C., D'Silva, D., Haward, M., et al. (2014). The short history of research in a marine climate change hotspot: from anecdote to adaptation in south-east Australia. *Rev. Fish Biol. Fish.* 24, 593–611.
- Ghodeswar, B. M. (2008). Building brand identity in competitive markets: A conceptual model. *J. Prod. Brand Manag.* 17, 4–12. doi: 10.1108/10610420810856468
- Glaser, B., and Strauss, A. (1967). *The Discovery of Grounded Theory: Strategies for Qualitative Research*. Chicago: Aldine.
- Guest, G., Bunce, A., and Johnson, L. (2006). How Many Interviews Are Enough? An Experiment with Data Saturation and Variability. *Field Methods* 18, 59–82. doi: 10.1177/1525822x05279903
- Guimarães, M. H., Pohl, C., Bina, O., and Varanda, M. (2019). Who is doing inter- and transdisciplinary research, and why? An empirical study of motivations, attitudes, skills, and behaviours. *Futures* 112:102441. doi: 10.1016/j.futures.2019.102441
- Haider, L. J., Hentati-Sundberg, J., Giusti, M., Goodness, J., Hamann, M., Masterson, V. A., et al. (2018). The undisciplinary journey: early-career perspectives in sustainability science. *Sustainability Sci.* 13, 191–204. doi: 10.1007/s11625-017-0445-1
- Hart, D. D., Bell, K. P., Lindenfeld, L. A., Jain, S., Johnson, T. R., Ranco, D., et al. (2015). Strengthening the role of universities in addressing sustainability challenges: The Mitchell Center for Sustainability Solutions as an institutional experiment. *Ecol. Soc.* 20:4.
- Hay, I. (2010). *Qualitative Research Methods in Human Geography*. Canada: Oxford University Press.
- Hein, C. J., Ten Hoeve, J. E., Gopalakrishnan, S., Livneh, B., Adams, H. D., Marino, E. K., et al. (2018). Overcoming early career barriers to interdisciplinary climate change research. *Wiley Interdiscip. Rev. Clim. Change* 9:e530. doi: 10.1002/wcc.530
- Hicks, C. C., Fitzsimmons, C., and Polunin, N. V. (2010). Interdisciplinarity in the environmental sciences: barriers and frontiers. *Environ. Conserv.* 37, 464–477. doi: 10.1017/s0376892910000822
- Howe-Walsh, L., and Turnbull, S. (2016). Barriers to women leaders in academic: tales from science and technology. *Stud. High. Edu.* 41, 415–428. doi: 10.1080/03075079.2014.929102
- Irwin, A., and Horst, M. (2016). Communicating trust and trusting science communication—some critical remarks. *J. Sci. Commun.* 15:L01.
- Kelly, R., Mackay, M., Nash, K. L., Cvitanovic, C., Allison, E. H., Armitage, D., et al. (2019). Ten tips for developing interdisciplinary socio-ecological researchers. *Soc. Ecol. Pract. Res.* 1, 149–161. doi: 10.1007/s42532-019-00018-2
- King, N., Horrocks, C., and Brooks, J. (2018). *Interviews in Qualitative Research*. Oaks, CA: SAGE Publications Limited.
- Lacey, J., Howden, M., Cvitanovic, C., and Colvin, R. M. (2018). Understanding and managing trust at the climate science–policy interface. *Nat. Clim. Change* 8, 22–28. doi: 10.1038/s41558-017-0010-z
- Lam, V. W., Allison, E. H., Bell, J. D., Blythe, J., Cheung, W. W., Frölicher, T. L., et al. (2020). Climate change, tropical fisheries and prospects for sustainable development. *Nat. Rev. Earth Environ.* 1, 440–454.
- Lang, D. J., Wiek, A., Bergmann, M., Stauffacher, M., Martens, P., Moll, P., et al. (2012). Transdisciplinary research in sustainability science: practice, principles, and challenges. *Sustainability Sci.* 7, 25–43. doi: 10.1007/s11625-011-0149-x
- Ledford, H. (2015). How to solve the world's biggest problems. *Nat. News* 525:308.
- Leibbrandt, A., Wang, L. C., and Foo, C. (2017). Gender quotas, competitions, and peer review: Experimental evidence on the backlash against women. *Manag. Sci.* 64, 3501–3516. doi: 10.1287/mnsc.2017.2772
- Lückerath-Rovers, M. (2013). Women on boards and firm performance. *J. Manag. Gover.* 17, 491–509. doi: 10.1007/s10997-011-9186-1
- Lyall, C., Bruce, A., Marsden, W., and Meagher, L. (2013). The role of funding agencies in creating interdisciplinary knowledge. *Sci. Public Policy* 40, 62–71. doi: 10.1093/scipol/scs121
- Maag, S., Alexander, T. J., Kase, R., and Hoffmann, S. (2018). Indicators for measuring the contributions of individual knowledge brokers. *Environ. Sci. Policy* 89, 1–9. doi: 10.1016/j.envsci.2018.06.002
- Marshall, N. A., Adger, N., Attwood, S., Brown, K., Crissman, C., Cvitanovic, C., et al. (2017). Empirically derived guidance for social scientists to influence environmental policy. *PLoS One* 12:e0171950. doi: 10.1371/journal.pone.0171950
- Marshall, N. A., Friedel, M., Van Klinken, R. D., and Grice, A. C. (2011). Considering the social dimension of contentious species: the case of buffel grass. *Environ. Sci. Policy* 14, 327–338. doi: 10.1016/j.envsci.2010.10.005
- Meadow, A. M., Ferguson, D. B., Guido, Z., Horangic, A., and Owen, G. (2015). Moving toward the deliberate co-production of climate science knowledge. *Weather Clim. Soc.* 7, 179–191. doi: 10.1175/wcas-d-14-00050.1
- Meyer, R., McAfee, S., and Whiteman, E. (2015). How California as mobilizing boundary chains to integrate science, policy and management for changing ocean chemistry. *Clim. Risk Manag.* 9, 50–61. doi: 10.1016/j.crm.2015.04.002
- Misra, S., Hall, K., Feng, A., Stipelman, B., and Stokols, D. (2011). *Collaborative Processes in Transdisciplinary Research. In Converging Disciplines*. New York, NY: Springer, 97–110.
- Mitchneck, B., Smith, J. L., and Latimer, M. (2016). A recipe for change: Creating a more inclusive academy. *Science* 352, 148–149. doi: 10.1126/science.aad8493
- Molas-Gallart, J., Tang, P., and Morrow, S. (2000). Assessing the non-academic impact of grant funded socio-economic research: Results from a pilot study. *Res. Eval.* 9, 171–182. doi: 10.3152/147154400781777269
- Nash, K. L., Blythe, J. L., Cvitanovic, C., Fulton, E. A., Halpern, B. S., Milner-Gulland, E. J., et al. (2020). To Achieve a Sustainable Blue Future, Progress Assessments Must Include Interdependencies between the Sustainable Development Goals. *One Earth* 2, 161–173. doi: 10.1016/j.oneear.2020.01.008
- Nash, K. L., Cvitanovic, C., Fulton, E. A., Halpern, B. S., Milner-Gulland, E. J., Watson, R. A., et al. (2017). Planetary boundaries for a blue planet. *Nat. Ecol. Evol.* 1, 1625–1634.
- Nielsen, M. W., Bloch, C. W., and Schiebinger, L. (2018). Making gender diversity work for scientific discovery and innovation. *Nat. Hum. Behav.* 2, 726–734. doi: 10.1038/s41562-018-0433-1
- Norström, A. V., Cvitanovic, C., Löf, M. F., West, S., Wyborn, C., Balvanera, P., et al. (2020). Principles for knowledge co-production in sustainability research. *Nat. Sustainability* 3, 182–190.
- Østergaard, C. R., Timmermans, B., and Kristinsson, K. (2011). Does a different view create something new? The effect of employee diversity on innovation. *Res. Policy* 40, 500–509. doi: 10.1016/j.respol.2010.11.004
- Palmer, L. (2018). Meeting the leadership challenges for interdisciplinary environmental research. *Nat. Sustainability* 1:330. doi: 10.1038/s41893-018-0103-3
- Parker, J. N., and Hackett, E. J. (2012). Hot spots and hot moments in scientific collaborations and social movements. *Am. Sociol. Rev.* 77, 21–44. doi: 10.1177/0003122411433763
- Patton, M. Q. (2002). *Qualitative Research and Evaluation Methods*. Oaks, CA: SAGE Publications.

- Pecl, G. T., Araújo, M. B., Bell, J. D., Blanchard, J., Bonebrake, T. C., and Chen, I. C. (2017). Biodiversity redistribution under climate change: Impacts on ecosystems and human well-being. *Science* 355:eaai9214.
- Penfield, T., Baker, M. J., Scoble, R., and Wykes, M. C. (2014). Assessment, evaluations, and definitions of research impact: A review. *Res. Eval.* 23, 21–32. doi: 10.1093/reseval/rvt021
- Perrow, C. (1979). *Complex Organisations—A Critical Essay*. New York, NY: McGraw-Hill, Inc.
- Pischke, E. C., Knowlton, J. L., Phifer, C. C., Lopez, J. G., Propato, T. S., Eastmond, A., et al. (2017). Barriers and solutions to conducting large international, interdisciplinary research projects. *Environ. Manag.* 60, 1011–1021. doi: 10.1007/s00267-017-0939-8
- Porter, A. L., Roessner, J. D., Cohen, A. S., and Perreault, M. (2006). Interdisciplinary research: meaning, metrics and nurture. *Res. Eval.* 15, 187–195. doi: 10.3152/147154406781775841
- Posner, S. M., and Cvitanovic, C. (2019). Evaluating the impacts of boundary-spanning activities at the interface of environmental science and policy: A review of progress and future research needs. *Environ. Sci. Policy* 92, 141–151. doi: 10.1016/j.envsci.2018.11.006
- Ravenscroft, J., Liakata, M., Clare, A., and Duma, D. (2017). Measuring scientific impact beyond academia: An assessment of existing impact metrics and proposed improvements. *PLoS One* 12:e0173152. doi: 10.1371/journal.pone.0173152
- Reed, M. S., Duncan, S., Manners, P., Pund, D., Armitage, L., Frewer, L., et al. (2018). A common standard for the evaluation of public engagement with research. *Res. All* 2, 143–162.
- Reed, M. S., Stringer, L. C., Fazey, I., Evely, A. C., and Kruijsen, J. H. J. (2014). Five principals for the practice of knowledge exchange in environmental management. *J. Environ. Manag.* 146, 337–345. doi: 10.1016/j.jenvman.2014.07.021
- Reinecke, S. (2015). Knowledge brokerage designs and practices in four European climate services: A role model for biodiversity policies? *Environ. Sci. Policy* 54, 513–521. doi: 10.1016/j.envsci.2015.08.007
- Roy, E. D., Morzillo, A. T., Seijo, F., Reddy, S. M., Rhemtulla, J. M., Milder, J. C., et al. (2013). The elusive pursuit of interdisciplinarity at the human-environmental interface. *Bioscience* 63, 745–753. doi: 10.1525/bio.2013.63.9.10
- Saldana, J. (2015). *The Coding Manual for Qualitative Researchers*. Oaks, CA: Sage.
- Shanley, P., and López, C. (2009). Out of the loop: Why research rarely reaches policy makers and the public and what can be done. *Biotropica* 41, 535–544. doi: 10.1111/j.1744-7429.2009.00561.x
- Shi, F., Teplitskiy, M., Duede, E., and Evans, J. A. (2019). The wisdom of polarized crowds. *Nat. Hum. Behav.* 3, 329–336. doi: 10.1038/s41562-019-0541-6
- Shiffman, D. S. (2012). Twitter as a tool for conservation education and outreach: what scientific conferences can do to promote live-tweeting. *J. Environ. Stud. Sci.* 2, 257–262. doi: 10.1007/s13412-012-0080-1
- Steffen, W., Rockström, J., Richardson, K., Lenton, T. M., Folke, C., Liverman, D., et al. (2018). Trajectories of the Earth System in the Anthropocene. *Proc. Natl. Acad. Sci.* 115, 8252–8259.
- Stern, N. (2016). *Building on Success and Learning from Experience: an Independent Review of the Research Excellence Framework*. London: Department for Business, Energy and Industrial Strategy.
- Stokols, D. (2014). “Training the next generation of transdisciplinary,” in *Enhancing Communication and Collaboration in Interdisciplinary Research*, eds M. O'Rourke, S. Crowley, S. Eigenbrode, and J. Wulforth (New York, NY: Oxford University Press), 56–81. doi: 10.4135/9781483352947.n4
- United Kingdom Research and Innovation (2019a). *Excellence with Impact*. Available online at: <https://bbsrc.ukri.org/innovation/maximising-impact/fostering-innovation/excellence-impact/> [accessed on May 15, 2019].
- United Kingdom Research and Innovation (2019b). *Global Interdisciplinary Research Hubs: Building Global Research Communities to Develop Innovative and Sustainable Solutions for Sustainable Development*. Swindon: United Kingdom Research and Innovation.
- Van Noorden, R. (2015). Interdisciplinary research by the numbers. *Nature* 525, 306–307. doi: 10.1038/525306a
- Vatsa, M. (2016). Leveraging Employer Branding for Organizational Success. *Rev. Manag.* 6, 9–13.

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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